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An overview of renewable energy utilization from municipal solid waste (MSW) incineration in Taiwan

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Abstract

Taiwan is an energy-importing nation with more than 97% of energy consumption supplied by imported fuels. In this regard, renewable energy like waste-to-energy is become attractive. The objective of this paper is to present an overview of energy utilization from the cogeneration system of municipal solid waste (MSW) incineration in recent years. The description is thus centered on MSW generation, incineration treatment and its energy utilization status. The energy policy relating to MSW-to-energy is also summarized in the paper. Finally, we present the regulatory system including Air Pollution Control Act, Energy Management Law and Statute for Upgrading Industries, which is not only to establish the environmental standards on MSW incineration facility, but also to provide economic and financial incentives to promote the use of MSW-to-energy.

Keywords: Waste-to-energy; Municipal solid waste; Promotion measure; Energy policy

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1. Introduction

Taiwan is located in the southeastern rim of Asia, facing the Pacific Ocean in the east and the Taiwan Strait in the west. The small island country with a total area of ca. 36,000 km^2 is about 377 km long and 142 km wide. By the end of 2003, Taiwan with a population of over 22 millions ranked second in population density in the world. Evidently, Taiwan is a densely populated island with only limited natural resources, and over 97% energy supply must depend on oversea imports [1]. Thus, energy plays a vital role in the economic and social development and life quality improvement in Taiwan.

With the rapid industrialization and economic development in the past three decades, heavy environmental loadings caused some serious environmental scenarios such as air quality deterioration, river water pollution, illegal dumping and non-sanitary landfill of industrial and municipal solid wastes [2]. As a result, Taiwan's Environmental Protection Administrations (EPA), the primary central government-level agency responsible for environmental issues, began to promulgate stringent regulation to establish an integrated waste management system for environmental protection.

Incineration is currently the primary municipal solid waste (MSW) treatment method adopted in Taiwan. To accelerate resolution of MSW treatment/disposal problems, Taiwan EPA subsidizes local government for construction of large-scale MSW incinerator to deal with the urgent need in urban areas. By the year of 2006 or 2007, it is expected that a total of 29 large-scale incinerators will be operating, generating lots of electricity per year as shown in Fig. 1 [2]. From the viewpoint of the preventive and sustainable waste management, Taiwan's government meanwhile began to further encourage and better fulfill the recycling and reuse of MSW since the early of 1990s, because the air toxics emitted from MSW incineration facilities have arisen many attentions. With regard to economic and financial incentives pertaining to energy conservation and efficiency, the laws ('Energy Management Law' and 'Statute for Upgrading Industries') were recently amended in January 2002 and February 2003, respectively, and related regulations were thereafter issued for further promoting energy utilization from MSW incineration.

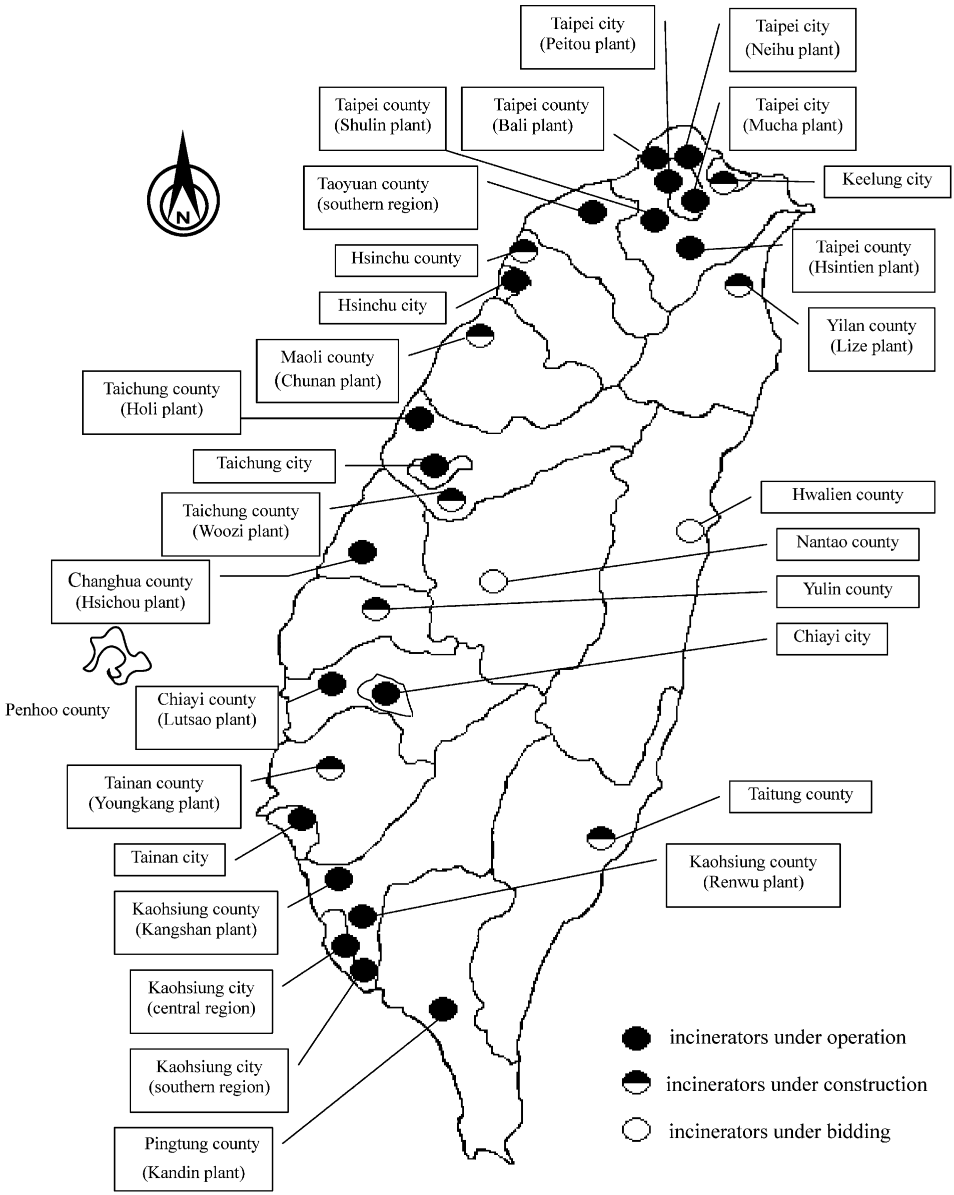


Fig. 1. The location distribution of large MSW incinerators in Taiwan.

Therefore, the objectives of this paper will present an updated review and innovative information on energy utilization from large-scale MSW incineration facilities, because its share of total renewable energy supply is currently estimated to over 85% in Taiwan [3]. These approaches will be expected to offer cost-effective measures for other developing countries. The term MSW used in the present paper refers to the ‘general waste’ by

the definition of Waste Disposal Act (WDA) in Taiwan. The main subjects covered in this paper are listed in the following key elements:

- MSW generation status
- MSW incineration for energy utilization
- Air pollution control regulations on MSW-to-energy
- Energy policy and promotion for MSW-to-energy

2. MSW generation status

According to the Article 2 of the WDA newly amended in October 2001, the wastes are classified into general wastes and industrial wastes. 'General wastes' are defined as follows: these wastes include garbage, excrement and urine, animal corpses in solid or liquid form generated by households or other non-industries, which have capacity to pollute the environment. Obviously, the general waste is almost identical to municipal solid waste (MSW), which is normally assumed to include all non-industrial community wastes such as residential wastes, commercial wastes and municipal service wastes (excluding treatment facilities).

As shown in Table 1, the quantity of MSW generated and thus collected by implementing agencies of local governments has increased up to the year of 1997–1998 and then decreased during the past decade. The change trend is parallel to MSW recycling program or resource recycling policy in the 1990s in Taiwan [4], resulting in the gradual reduction of quantity of MSW collected and thereafter treated. According to 'Yearbook of Environmental Protection Statistics' [5], the following combustible materials were found

Table 1
Amount of MSW collected, and treatment methods during 1991–2003 in Taiwan[a]

Year	Amount collected (metric ton)	Amount recycled (metric ton)	Treatment/disposal		
			Incineration (%)	Sanitary landfill (%)	Others[b] (%)
1991	7,239,000	N.A.[c]	0.4	59.7	39.9
1992	7,979,000	N.A.	3.2	63.6	33.2
1993	8,217,000	N.A.	3.0	62.0	35.0
1994	8,493,000	N.A.	4.9	65.6	29.5
1995	8,708,000	N.A.	14.9	50.1	35.0
1996	8,713,000	N.A.	15.6	55.2	29.2
1997	8,882,000	320,000	19.0	57.8	23.2
1998	8,882,000	554,000	19.6	63.0	17.4
1999	8,566,000	625,000	23.6	62.6	13.8
2000	7,854,000	854,000	41.0	48.5	10.5
2001	7,255,000	1,056,000	51.5	41.3	7.2
2002[d]	6,734,000	1,242,000	64.2	34.8	1.0
2003[d]	6,161,000	1,379,000	N.A.	N.A.	N.A.

[a] Source: [5].
[b] For example, composting and dumping.
[c] Not available.
[d] Source: [6].

Table 2
Physical composition, chemical analysis and energy content of residential MSW in Taiwan[a]

Properties	1992	1995	1998	2001	2002
Physical composition (on dry base)					
Paper (%)	24.86	32.17	32.77	26.55	30.01
Textiles (%)	3.97	6.21	5.27	4.81	3.65
Garden/trimmings (%)	5.06	5.82	4.81	4.06	4.43
Food wastes (%)	25.73	17.94	18.29	27.32	23.34
Plastics (%)	19.14	18.27	20.14	21.10	20.23
Leather/rubber (%)	1.73	0.88	0.83	0.48	0.60
Metal (%)	7.07	6.05	5.66	3.53	3.07
Glass (%)	7.69	5.59	5.84	5.03	4.11
Ceramics/china (%)	0.83	1.64	0.71	0.56	0.58
Stone/sand (%)	1.48	2.11	1.21	0.82	0.98
Others (%)	2.44	3.32	4.47	5.74	9.00
Approximate analysis (on wet base)					
Combustibles (%)	31.88	37.46	36.34	32.86	37.75
Ash (%)	16.15	14.40	12.60	11.34	11.01
Moisture (%)	51.97	48.14	51.06	55.80	51.24
Energy content (as discarded)					
High calorific value (kcal/kg)	1760	2235	2193	1969	2184
Low calorific value (kcal/kg)	1294	1742	1739	1541	1712

[a] Source: [5].

in MSW (dry basis): paper 25–36%, textiles 4–6%, garden/trimmings 3–6%, food wastes 18–28%, plastics 18–22%, and leather/rubber 1–2%, as shown in Table 2. The data of energy content in the Taiwan's MSW is also listed in Table 2. Generally, MSW with a high heating value (greater than 5000 kJ/kg or 1200 kcal/kg), low moisture content (less than 50%), and low ash content (less than 60%) can be burned without additional fuel [7]. As expected, the energy content values (as discarded basis) of MSW in Taiwan are available for treatment by incineration.

3. MSW incineration for energy utilization

According to the data examined by Taiwan EPA and shown in Table 1 [6], 64.2% (approx. 4323 thousand metric tons) of MSW by incineration, 34.8% (approx. 2343 thousand metric tons) of MSW by sanitary landfill, and 1.0% (approx. 68 thousand metric tons) of MSW by other methods in 2002. In contrast to the data of 1990s also listed in Table 1, the quantity of MSW treated by incineration method has greatly increased during the past decade. In 1991, less than 1% of MSW was treated by incineration process. Since then, Taiwan EPA has adopted a strategy favoring incineration as the primary treatment and sanitary landfill as a supplement. According to the Engineering Project for the Construction of Refuse Incineration Plants in Taiwan approved by Executive Yuan in 1990 [2], 21 large-scale incinerators will have been constructed before 2005 shown in Table 3, by that time the MSW incineration rates can

Table 3
Implementation of the construction project of publicly owned MSW incineration facilities in Taiwan[a]

No.	Location	Design capacity (Metric ton/day)	Design power generation (kW)	Remark (Year-on-line)
1	Taipei city (Neihu plant)	900	5200	In operation (January, 1991)
2	Taipei city (Mucha plant)	1500	12,000	In operation (March, 1995)
3	Taipei city (Peitou plant)	1800	42,000	In operation (September, 1999)
4	Taipei county (Hsintien plant)	900	14,670	In operation (November, 1995)
5	Taipei county (Shulin plant)	1350	22,100	In operation (October, 1995)
6	Taipei county (Bali plant)	1350	31,300	In operation (July, 2001)
7	Hsinchu city	900	23,000	In operation (February, 2001)
8	Taichung county (Holi plant)	900	25,000	In operation (May, 1997)
9	Taichung city	900	13,000	In operation (August, 2000)
10	Changhua county (Hsichou plant)	900	21,500	In operation (January, 2001)
11	Chiayi county (Lutsao plant)	900	25,000	In operation (December, 2001)
12	Chiayi city	300	2,310	In operation (July, 2001)
13	Tainan county (Youngkang plant)	900	21,500	Under construction
14	Tainan city	900	13,700	In operation (August, 1999)
15	Kaohsiung county (Kangshan plant)	1350	31,000	In operation (November, 2001)
16	Kaohsiung county (Renwu plant)	1350	31,000	In operation (November, 2001)
17	Kaohsiung city (central region)	900	23,100	In operation (September, 1999)
18	Kaohsiung city (southern region)	1800	49,000	In operation (January, 2000)
19	Pingtung county (Kandin plant)	900	23,000	In operation (December, 2000)
20	Keelung city	600	14,300	Under construction
21	Yilan county (Lize plant)	600	14,300	Under construction
Sum		21,900	450,980	

[a] Source: [2].

be expected to reach 70% and above. It is noted that these mass-burn incinerators will generate lots of marketable electricity through steam turbine-generator (cogeneration) system based on design power generation listed in Table 3. In terms of Build-Operate-Transfer (BOT) and Build-Operate-Own (BOO), Taiwan EPA further encourages the private sector to construct mass burn incinerators since 1996, and will actively supervise and assist local governments in the bid tendering and construction-related operations in order to ensure the completion of 15 plants (initial)/eight plants (revised) by the year 2006 or 2007, as shown in Table 4. It should also be noted that the ratio of energy generation from MSW incineration facilities to the total generation of renewable energy is unexpectedly high (about 82%) in 1999 [8].

Table 4
Implementation of the construction project of privately constructed MSW incineration facilities in Taiwan[a]

No.	Location	Promotion type	Design capacity (Metric ton/day)	Implementation status
1	Taoyuan county (southern region)	BOO[b]	1200	In operation (September, 2001)
2	Hsinchu county	BOO	300	Under construction
3	Maoli county (Chunan plant)	BOT[c]	500	Under construction
4	Taichung county (Woozi plant)	BOT	600	Under construction
5	Nantao county	BOO	500 (400)[d]	Under bidding[e]
6	Changhua county	BOO	800 (0)	Cancelled
7	Yulin county	BOO	600	Under construction
8	Taitung county	BOO		Under construction
9	Taipei county	BOO	300 (0)	Cancelled
10	Taoyuan county (Northern region)	BOO	800 (0)	Cancelled
11	Taichung city	BOT	600 (0)	Cancelled
12	Taichung county (Ta-an plant)	BOT	500 (0)	Cancelled
13	Tainan county (Chiku plant)	BOT	900 (0)	Cancelled
14	Hwalien county	BOT	400 (350)	Under bidding[e]
15	Penhoo county (Hoosi plant)	BOT	200 (0)	Cancelled
Sum			8500 (4250)	

[a] Source: [2].
[b] Denoted as build-operate-own.
[c] Denoted as build-operate-transfer.
[d] Number in parentheses denote the new design capacity after revising.
[e] Because of environmental and economic benefits, the construction cancel is under consideration.

4. Air pollution control regulations on MSW-to-energy

In Taiwan, the basic law governing and promoting air pollution control and prevention is the Air Pollution Control Act (APCA), which was initially passed in May 1975, recently amended in June 2002. The goal of this act is set to prevent and control air pollution, safeguard public health and the living environment. Under the authorization of the APCA, there are two important provisions or regulations concerning emission standards for MSW-to-energy facilities, which are briefly described as follows:

4.1. MSW incinerator air pollutants emission standards

MSW incineration with heat recovery (i.e. cogeneration) is one of important energy utilizations in Taiwan. However, it is well known that the thermal process has the potential of emitting a diverse type of air pollutants to the environment. These potential emissions may arise from compounds (e.g. heavy metals) present in the waste stream, are formed as a part (e.g. particulate and acid gases) of the normal combustion process, or are formed as a result (e.g. carbon monoxide) of incomplete combustion. Therefore, Taiwan EPA first promulgated the air pollution control standards for controlling MSW

incinerator emissions in November 1992 [1]. It is noted that MSW incinerators in Taiwan are facing the decline of general waste generation (Table 1) because of the promotion on resource recovery, green consumption and green procurement since the early of 1990s. To maintain the stable operation of cogeneration in the MSW incineration facilities, some of these incinerators are being permitted to incinerate general industrial wastes from workshops such as wood wastes and agricultural wastes by local government authorities of Taiwan.

4.2. Waste incinerator dioxin control and emission standards

While there is concern regarding the emissions of acid gases and heavy metals from waste incinerators, probably the most controversial pollutants from incinerator emissions are the categories of chlorinated organics (i.e. dioxins/furans, or referred to PCDDs/PCDFs), which may be formed as a result of incomplete combustion and have been found in the stack gas of MSW and industrial waste incinerators [9,10]. These compounds are of concern mainly due to their high toxicity in the laboratory animals, and endocrine-disrupting in the wildlife and humans [10]. With the policy on MSW incinerator construction project of 1990s in Taiwan, it was estimated that there are over 29 large-scale MSW incineration facilities to be operated in the end of 2006 or 2007 that may be ranked No. 1 in large-scale incinerator density in the world. It implies that dioxin emissions from these incinerators may cause a seriously adverse effect on human health. Therefore, Taiwan EPA first promulgated the dioxins emission standard for MSW incinerators in August 1997 under the authorization of APCA. Basically, the emission standards stipulate that dioxin level of incinerator stack must comply with the standard limit of 0.1 ng TEQ/Nm^3, which may be the most stringent regulation on dioxin control in the world [11]. The term TEQ is the abbreviation of toxicity equivalency quantity, which is based on the internation toxicity equivalency factor of 2,3,7,8-TCDD. According on the current dioxin monitoring data for 19 large-scale MSW incinerators under operation in Taiwan, all of the dioxin emission concentrations are below the standard limit of 0.1 ng TEQ/Nm^3, as shown in Table 5, because these facilities have adopted the best available control technologies such as operation modification and activated carbon adsorption [12].

5. Energy policy and promotion for MSW-to-energy

In response to the impacts of energy crisis and changes in the 1970s, ‘The Energy Policy of the Taiwan Area’ was first promulgated in April 1973 under the approval of Executive Yuan. Thereafter, the energy policy was further revised four times: in 1979, 1984, 1990 and 1996. In May 1998, a National Energy Conference was held in Taipei city for the purposes of formulating strategies and measures in response to dramatic changes in the domestic and international energy situations, economic situations and environmental issues, especially in climatic change. Current energy policy in Taiwan will aim at six targets: stabilizing energy supply, promoting energy efficiency, deregulating energy

Table 5
Monitoring data of dioxin concentrations of publicly owned MSW incineration facilities in Taiwan[a]

Location	Dioxin concentration (ng TEQ/Nm^3)[b]	Examination date	No. of examination
Taipei city (Neihu plant)	0.018–0.049	March/2002, April/2003	20
Taipei city (Mucha plant)	0.02–0.045	February/2001, March/2003	3
Taipei city (Peitou plant)	0.022	September/2002	1
Taipei county (Hsintien plant)	0.038–0.048	June/2002	2
Taipei county (Shulin plant)	0.015–0.048	October/2002	3
Taipei county (Bali plant)	0.035–0.048	April/2002, July/2002, January/2003	3
Taoyuan county (southern region)	0.054–0.058	August/2002, February/2003	8
Hsinchu city	0.065–0.071	December/2002	2
Taichung county (Holi plant)	0.013–0.079	September/2002, April/2003	4
Taichung city	0.024–0.035	February/2002	6
Changhua county (Hsichou plant)	0.054–0.068	November/2002, January/2003	8
Chiayi county (Lutsao plant)	0.017–0.023	July/2002, January/2003	2
Chiayi city	0.011–0.048	March/2003	2
Tainan city	0.019–0.088	July/2002, March/2003	3
Kaohsiung county (Kangshan plant)	0.048–0.077	May/2002, September/2002, April/2003	11
Kaohsiung county (Renwu plant)	0.01–0.071	June/2002	3
Kaohsiung city (central region)	0.041–0.081	September/2001, April/2002, September/2002	2
Kaohsiung city (southern region)	0.013–0.079	December/2001, June/2002, November/2002, May/2003	4
Pingtung county (Kandin plant)	0.017–0.032	July/2001, March/2003	2

[a] Source: [12].
[b] Emission standards in Taiwan: 0.1 ng TEQ/Nm^3.

enterprise, enhancing energy safety and environmental protection, reinforcing energy research and development, promoting energy education and dissemination [13].

In order to encourage the use of the cogeneration energy in Taiwan, current promotion regulations relating to MSW-to-energy utilization are mainly based on the Energy Management Law (EML), which was originally promulgated and became effective in August 1980 and was recently revised in January 2002. The principle purpose of the Law is to upgrade energy management and aim at rational and efficient utilization of energy for pursuing the sustainable development. According to the Article 10 of newly revised EML, important features concerning the aspects of MSW-to-energy include as follows:

(1) Where the amount of steam generated by an energy user meet with the level set up by the central competent authority, the user should install a cogeneration system.
(2) The energy user may ask the local vertical integrated utilities to purchase its excess power. The measures regarding the rates for the purchase of excess power, the central

Table 6
Statistics of electricity generation from MSW incineration facilities during the year of 2003 in Taiwan[a]

Location	Minimum LHV[b] designed (kcal/kg)	Amount of MSW incinerated (metric ton)	Amount of electricity generated (kW h)	Amount of electricity sold (kW h)[c]
Taipei city (Neihu plant)	1350	144,970	31,734,000	14,642,000
Taipei city (Mucha plant)	1600	223,719	61,837,000	34,166,000
Taipei city (Peitou plant)	2400	336,904	142,308,000	93,264,000
Taipei county (Hsintien plant)	1552	251,297	116,107,000	91,052,000
Taipei county (Shulin plant)	1553	351,307	163,422,000	132,557,000
Taipei county (Bali plant)	2305	456,352	208,566,000	169,003,000
Taoyuan county (southern plant)	2300	436,564	252,001,000	218,639,000
Hsinchu city	2300	270,513	154,775,000	125,704,000
Taichung county (Holi plant)	2300	285,254	166,095,000	136,807,000
Taichung city	1500	228,111	96,946,000	74,283,000
Changhua county (Hsichou plant)	2300	277,812	141,593,000	109,641,000
Chiayi county (Lutsao plant)	2500	303,555	179,605,000	149,687,000
Chiayi city	1350	84,536	20,186,000	13,236,000
Tainan city	1600	221,377	105,707,000	81,431,000
Kaohsiung county (Kangshan plant)	2500	366,980	204,286,000	163,814,000
Kaohsiung county (Renwu plant)	2400	338,023	182,830,000	150,833,000
Kaohsiung city (central region)	1900	245,923	78,148,000	48,078,000
Kaohsiung city (southern region)	2500	390,853	192,737,000	142,829,000
Pingtung county (Kandin plant)	2200	256,686	117,119,000	85,363,000

[a] Source: [2].
[b] Low heating value.
[c] Sold to Taiwan power company, a government-owned enterprise.

competent authority shall stipulate the tie-in between the systems of the energy user and the vertical integrated utilities, and the method of purchasing electricity energy.

Under the authorization of the Article, the Ministry of Economic Affairs (MOEA) in September 2002 has promulgated the regulation, known as 'Regulation of Implementation for Cogeneration System'. Table 6 lists the operation status of 19 large-scale MSW incinerators, including electricity generation and its amount sold out. From the data in

Table 6 [13], the percentage ratio of total electricity generation from MSW-to-energy (2.616×10^{9} kW h) to total electricity generation (1.738×10^{11} kW h) was about 1.51% during the year of 2003 in Taiwan, showing that the efficient utilization of MSW-to-energy is very significant.

With respect to the economic and financial promotions on MSW-to-energy, the promotion regulations are mainly based on the Statute for Upgrading Industries (SUI), which was originally promulgated and became effective in December 1990. Under the authorization of newly revised SUI, the Ministry of Finance (MOF) has first promulgated ‘Regulation of Tax Deduction for Investment in the Procurement of Equipments and/or Technologies by Energy conservation, or emerging/Clean Energy Organizations’ in July 1997. The regulation provides these specified organizations with incentives to procure energy conservation equipment in the form of a 2-year accelerated-depreciation plan, a 13% tax credit, and low-interest loams [3].

6. Conclusion and prospects

Over the past decade, energy supply/consumption relating to air quality and global warming has been the focus of environmental legislation and economic development for pursuing sustainable development and raising energy conservation in Taiwan. From the historical information and data presented here, it is obvious that the energy utilization from MSW incineration has been relatively high compared to total renewable energy generation and/or total cogeneration. On the other hand, Taiwan EPA has been promoting widespread use of the ‘4-in-1 Recycling system’ and ‘green consumption or ‘Green Mark’ since the early of 1990s. As a result, recycling rate is growing while the amount growth of MSW is moderating. Undoubtedly, the impact of resource recycling on the operation of MSW incineration is obviously negative. To greatly promote energy utilization from MSW treatment in Taiwan, the following measures are recommended and enhanced:

- Give priority in technological assistances to enhance thermal efficiency of the cogeneration system in the MSW incineration facility.
- Permitted to incinerate general industrial wastes from workshops such as wood wastes and agricultural wastes in response to the decreasing trend of MSW generation.
- Develop the manufacturing technology of refuse-derived fuel (RDF) from MSW for promoting its energy utilization and industrial applications.
- Research the manufacturing technology of liquid fuel by pyrolysis of MSW with high content of organic carbon.
- Focus MSW-to-energy on sanitary landfill gas (LFG) from the viewpoint of net greenhouse gas mitigation and air quality attainment.

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